Conformal behavior of the 12 flavor SU(3) system

BSM workshop, FNAL, Oct 16

Anna Hasenfratz
University of Colorado

Outline

- Spurious fixed points and their effect in the strong coupling

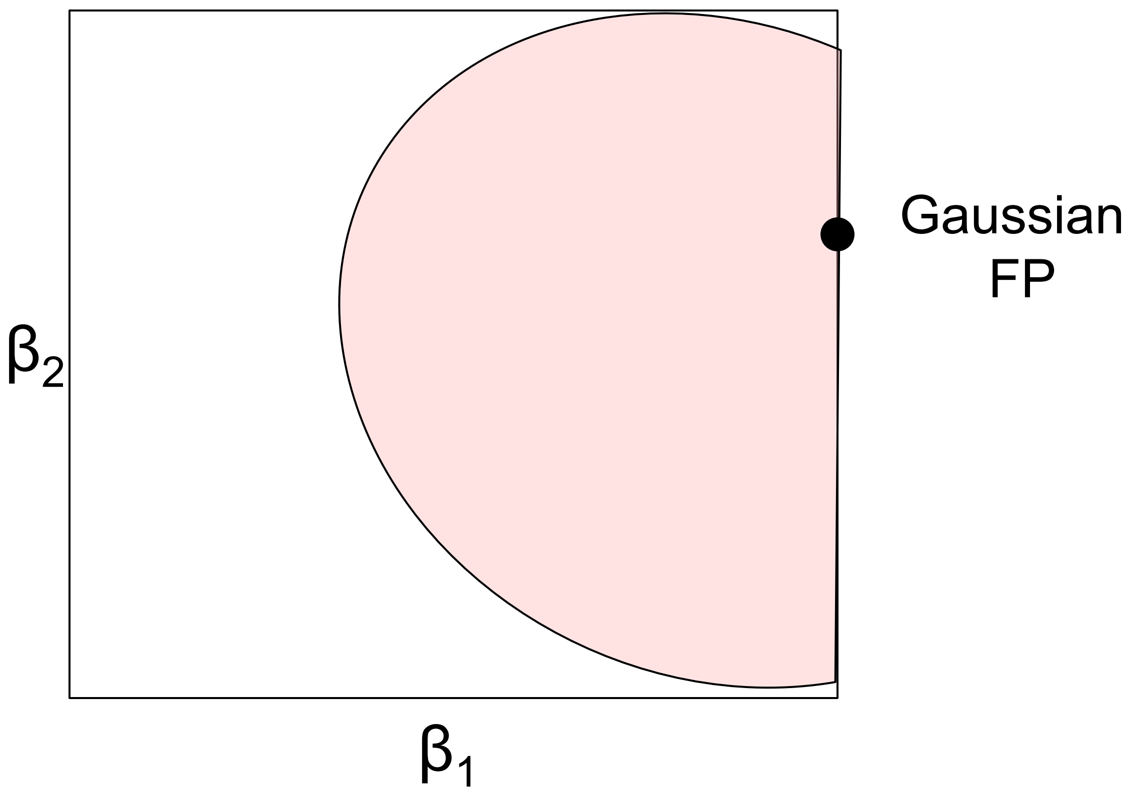
- SU(3) gauge system with 12 flavors
  - MCRG with improved gauge action
    - → Emergence of an IRFP (A.H. 1106.5293)
  - The phase structure at zero and finite temperature
    - → Phases in the strong coupling

      (A. Cheng, A.H., D. Schaich, in preparation)

Fixed points and their basin of attraction

In QCD like systems continuum limit is defined at the Gaussian UVFP

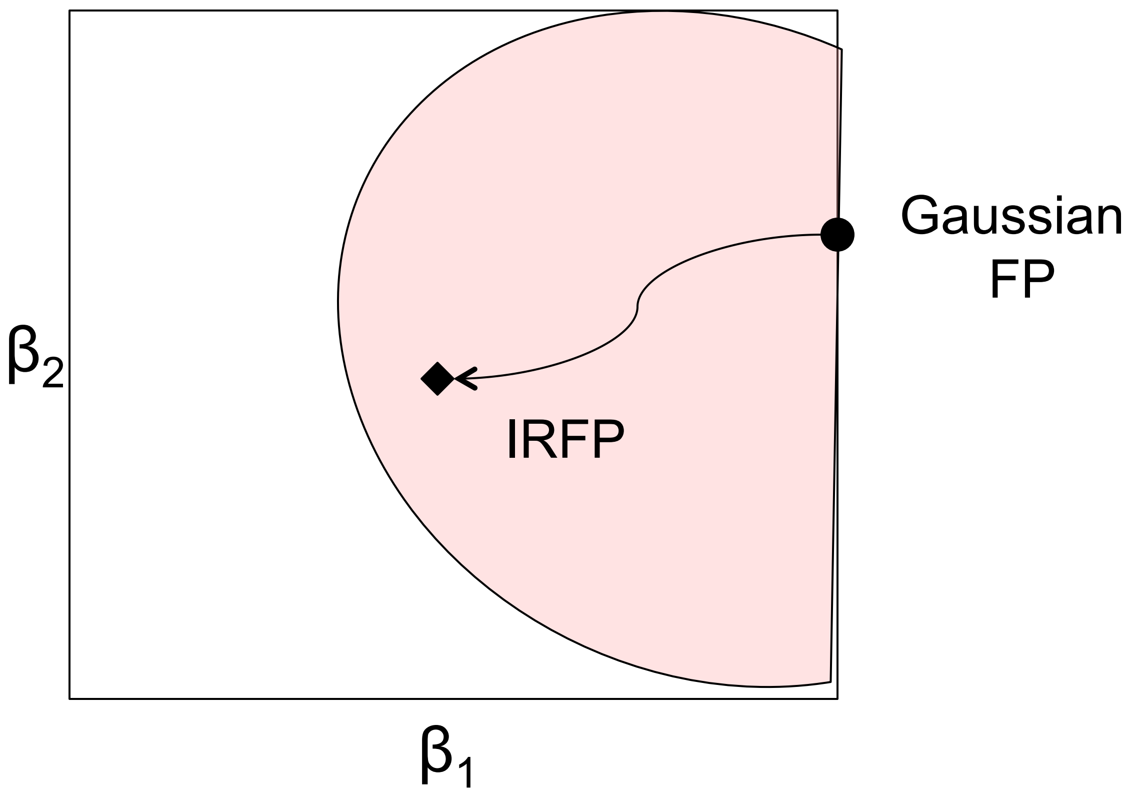
Continuum scaling is expected in the basin of attraction of G-FP



Fixed points and their basin of attraction

In conformal systems there is a new IRFP

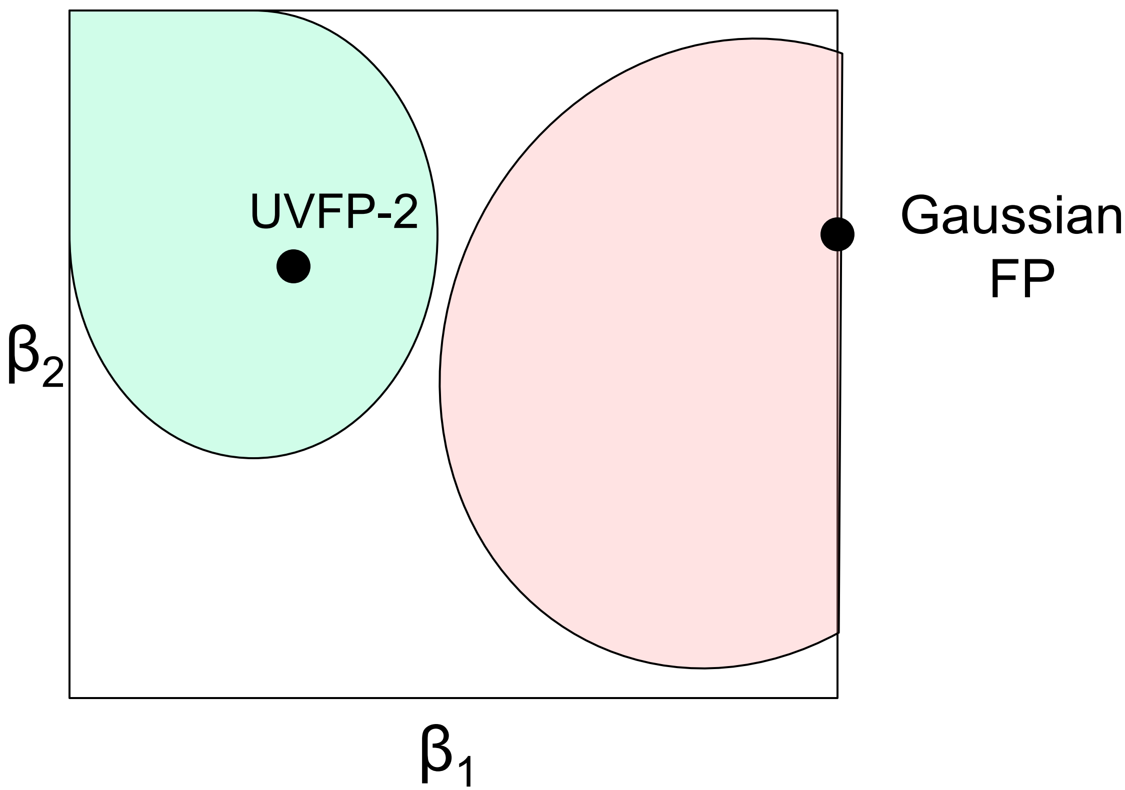
- asymptotically free around G-FP,
- the conformal behavior in the infrared around the IRFP



Fixed points and their basin of attraction

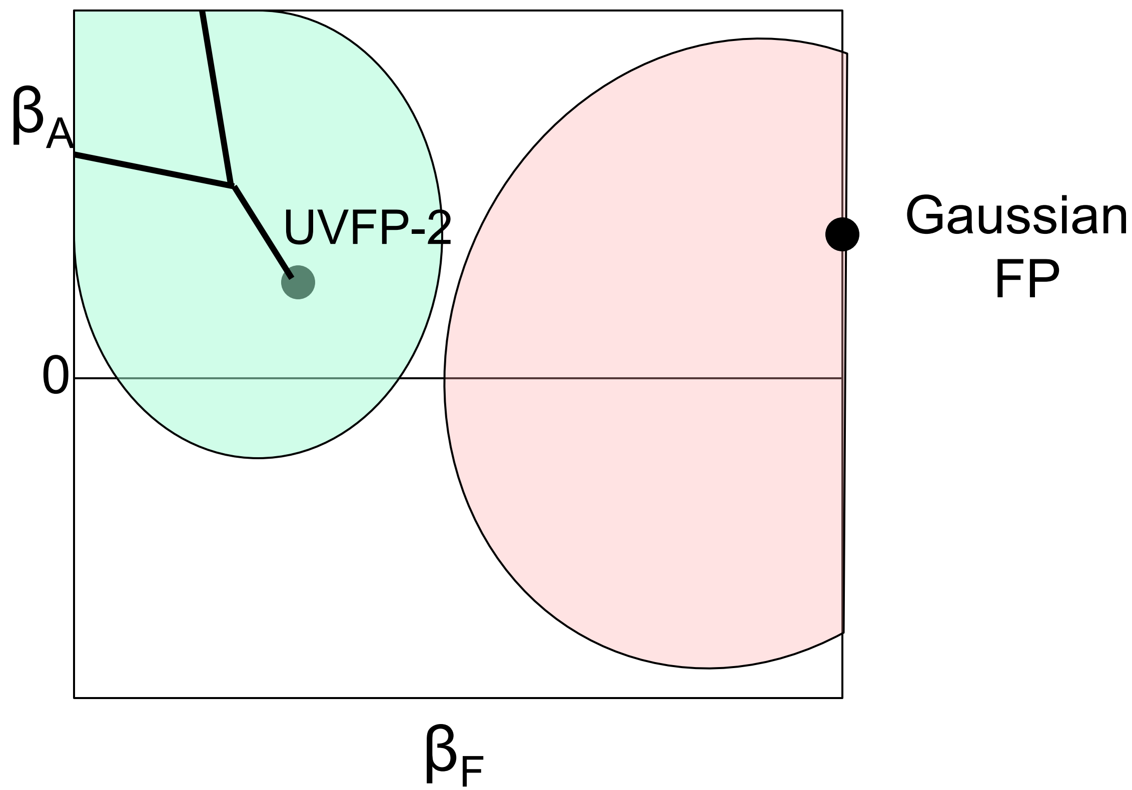
If there are two UV fixed points, continuum limit can be defined at both.

The basin of attractions are exclusive, stay in one or the other to get desired continuum scaling!



Fixed points and their basin of attraction

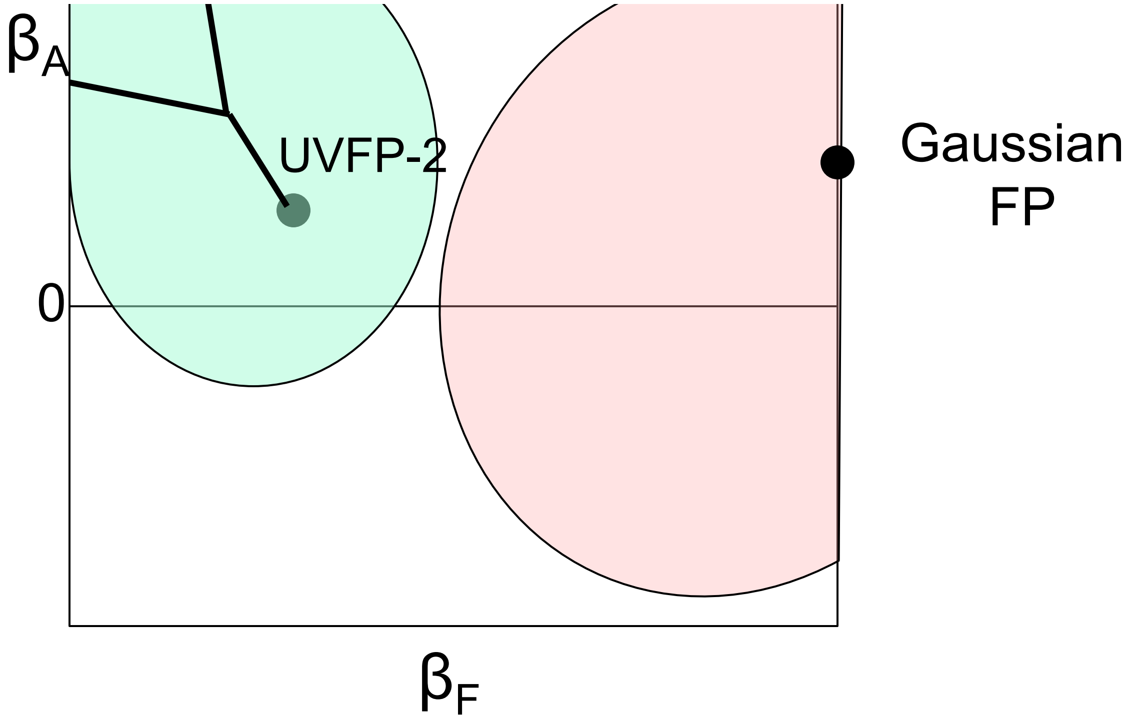
Pure gauge SU(2), SU(3) has this structure in the fundamental-adjoint plaquette plane: 1st order transitions ending in a 2nd order endpoint



Is UVFP-2 a problem?

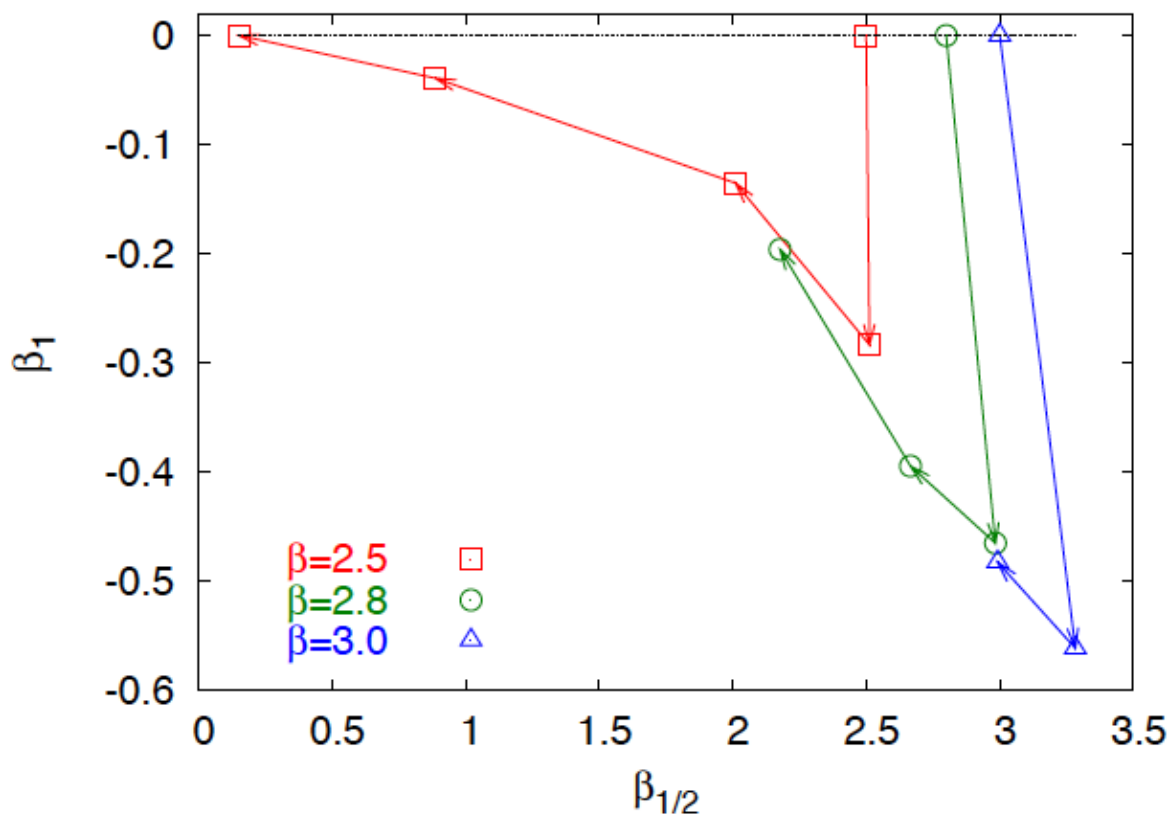
- Not for QCD simulations, those are on the weak coupling side.
- BSM models are strongly coupled and simulations can end up in the wrong FP basin

This is a problem for spectral studies as well, not only MCRG!



RG flow in the fundamental-adjoint plane

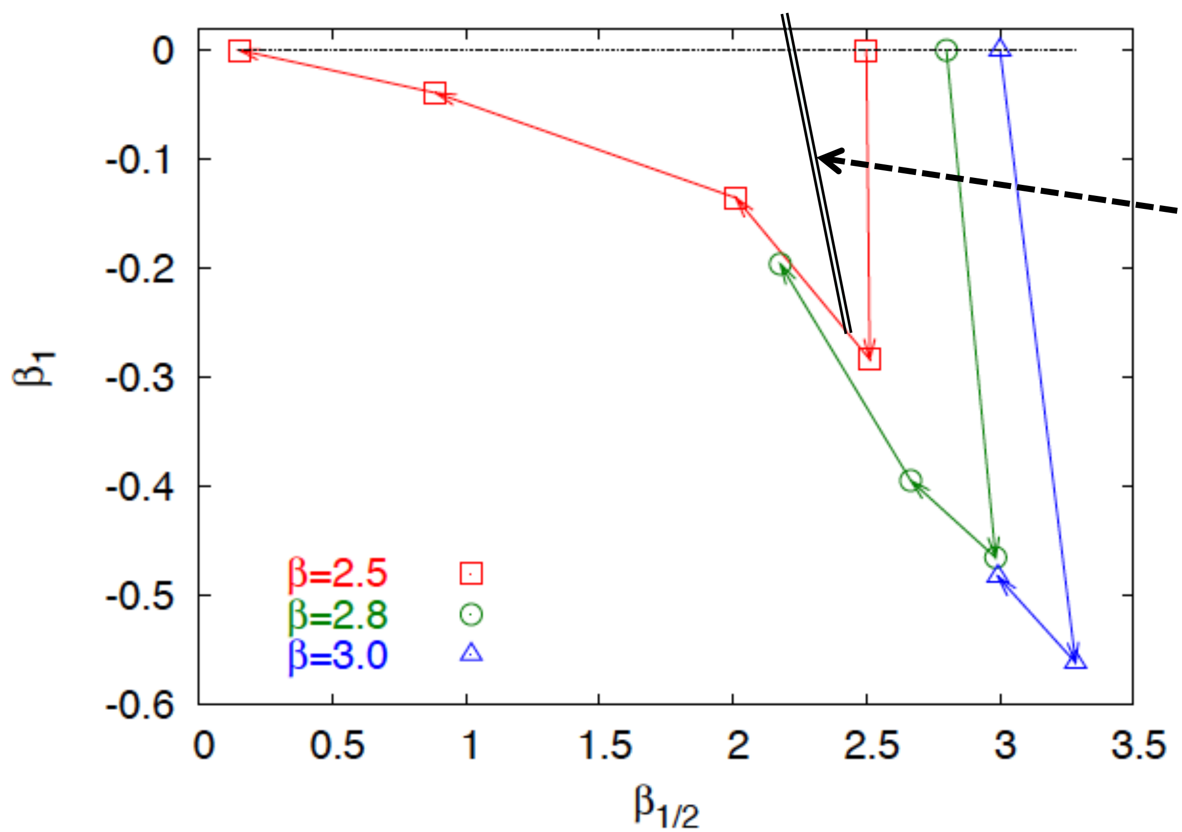
RG flow in pure gauge SU(2) Tomboulis,Velitski (hep-lat/0702015)
The flow runs away from the first order line/end point:



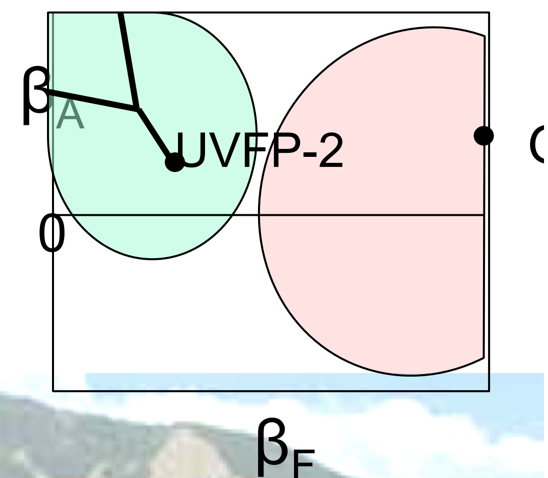
RG flow in the fundamental-adjoint plane

RG flow in pure gauge SU(2) — Tomboulis,Velitski (hep-lat/0702015)

The flow runs away from the first order line/end point:



Extension of the first order line

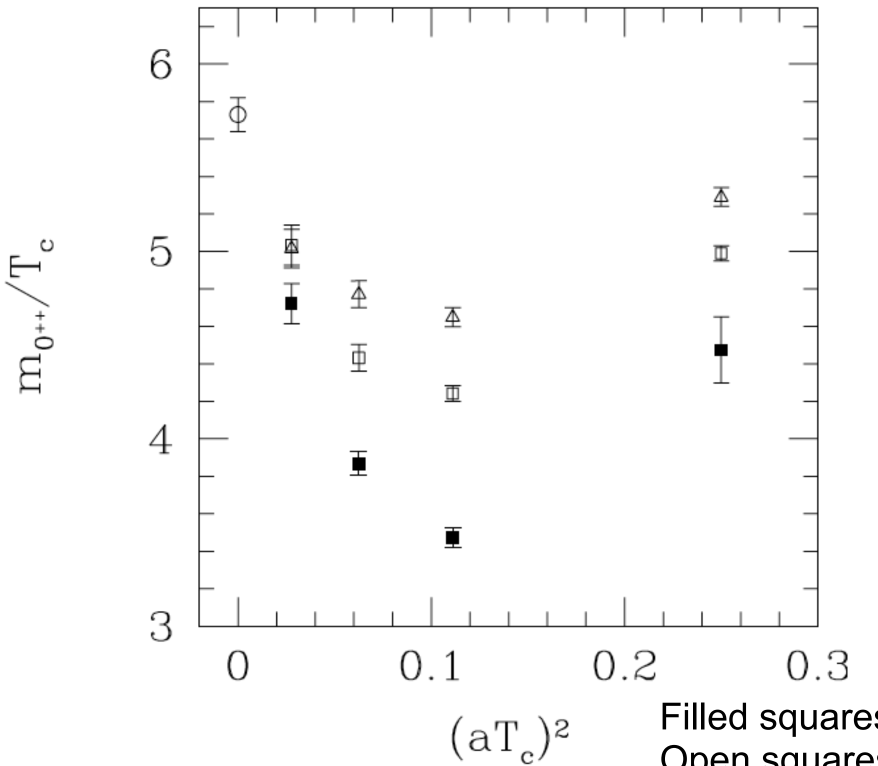


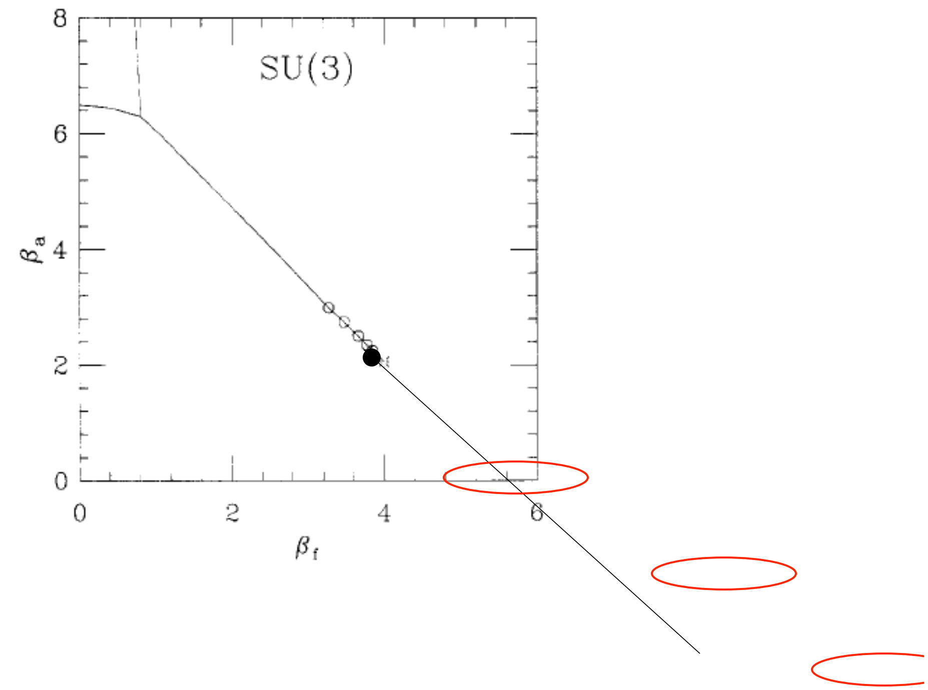
Scaling in the fundamental-adjoint gauge action

SU(3) pure gauge theory

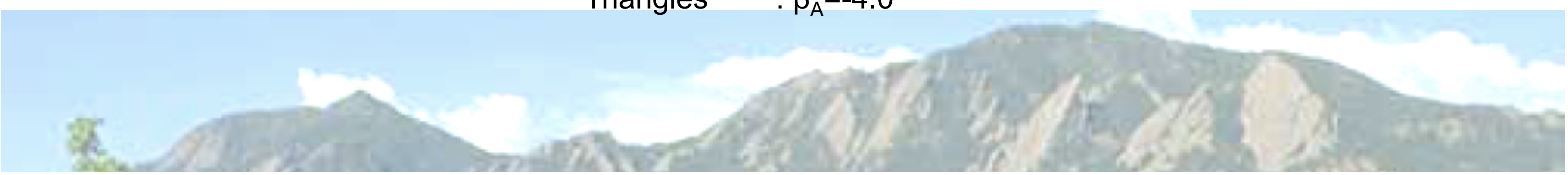
Hasenbusch,Necco JHEP08(2004)005:

Test the scaling of the glueball, T_c and r_0 at β_A=0, - 2.0, - 4.0





Filled squares: β_A=0
Open squares: β_A=-2.0
Triangles : β_A=-4.0

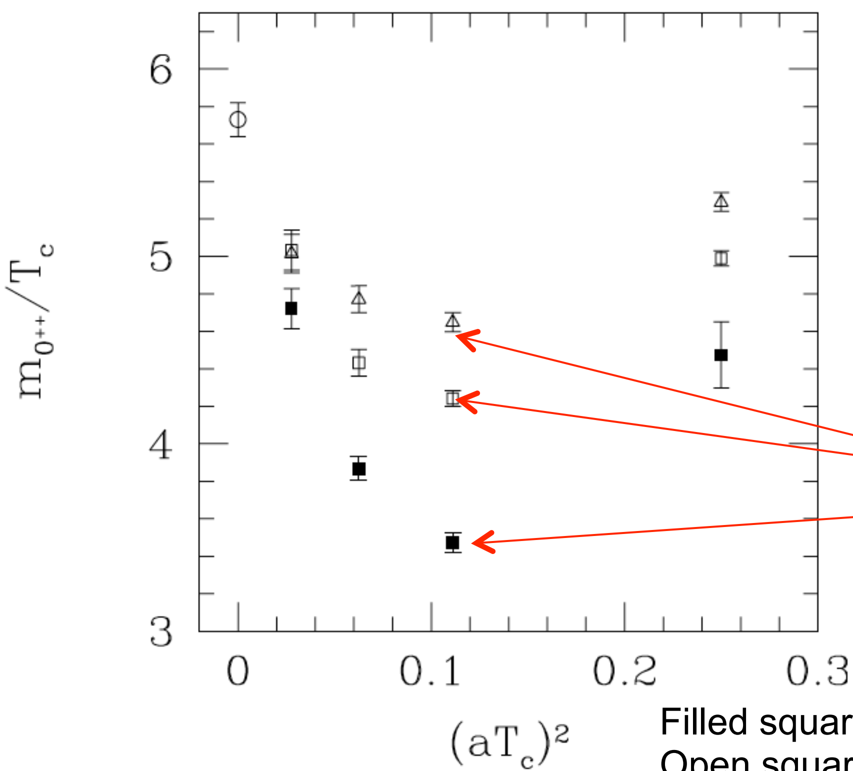


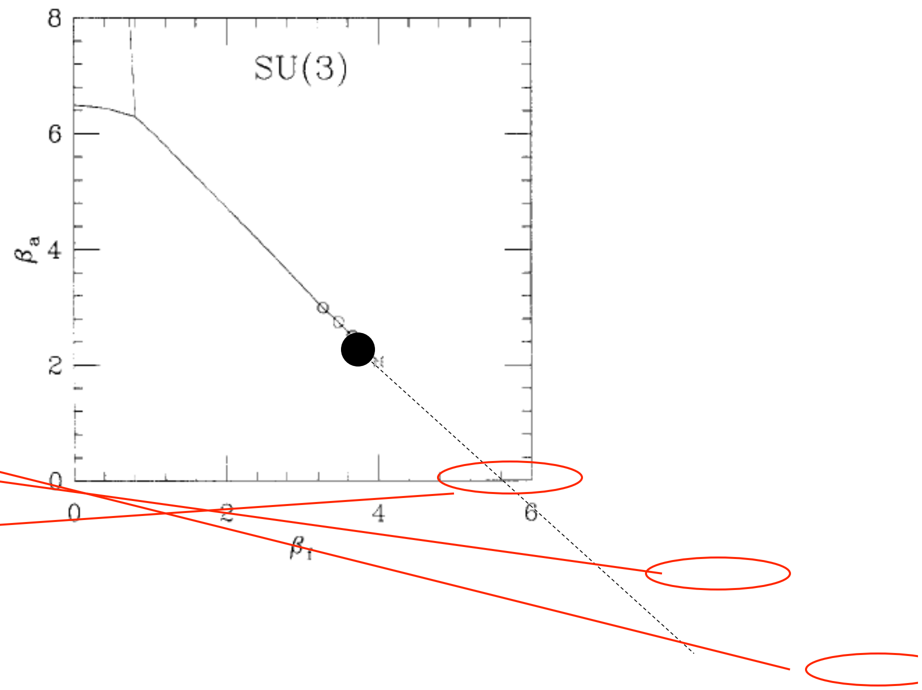
The fundamental-adjoint gauge action

SU(3) pure gauge theory

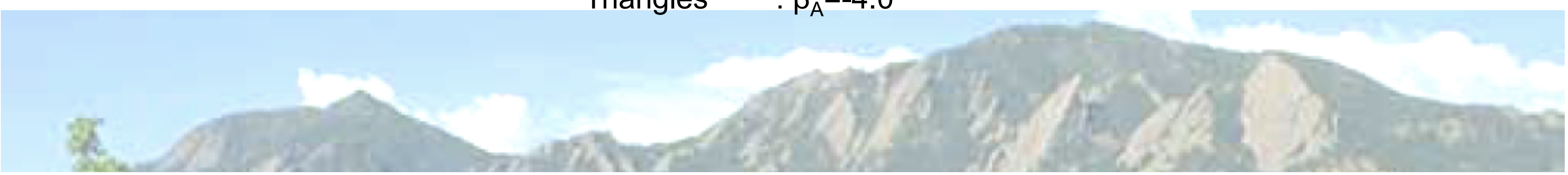
Hasenbusch,Necco JHEP08(2004)005:

Test the scaling of the glueball, T_c and r_0 at β_A=0, - 2.0, - 4.0





Filled squares: β_A=0
Open squares: β_A=-2.0
Triangles : β_A=-4.0

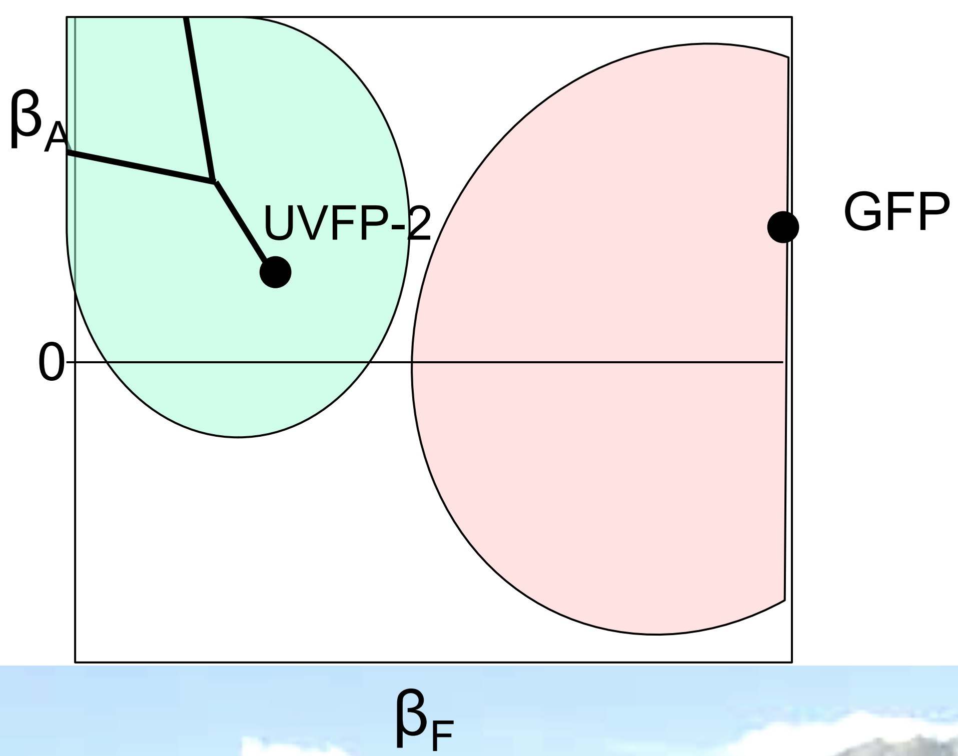


RG flow in the fundamental-adjoint plane

In between region:

- Is the flow controlled by G-FP or 2-UVFP or neither?
- MCRG suggests that it is a "no-man's land"

(A.H, O. Henrikson,G. Petropoulos)



Implication for BSM models

Strongly coupled systems often must be studied at strong bare coupling

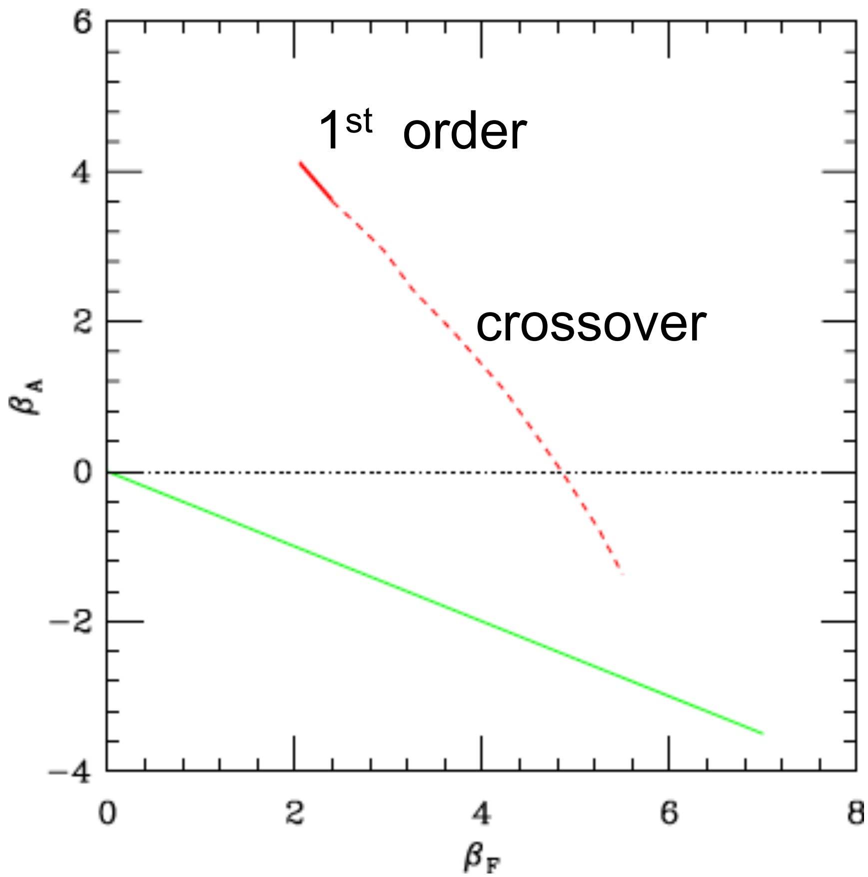
→ lattice artifacts can bring in spurious fixed points & unphysical behavior

→ if one is not careful, one might end up in the basin of attraction of the wrong fixed point!

SU(3) gauge with N_f=12 fundamental flavors

- Controversial system, likely very close to the conformal window.
- I use nHYP staggered fermions (very good taste restoration) with fundamental+adjoint plaquette gauge action
- Fermion masses are tiny: depending on the volume and RG steps, am=0.0025-0.02.
  For all practical purposes the simulations can be considered to be in the chiral limit

SU(3) gauge with N_f=12 fundamental flavors

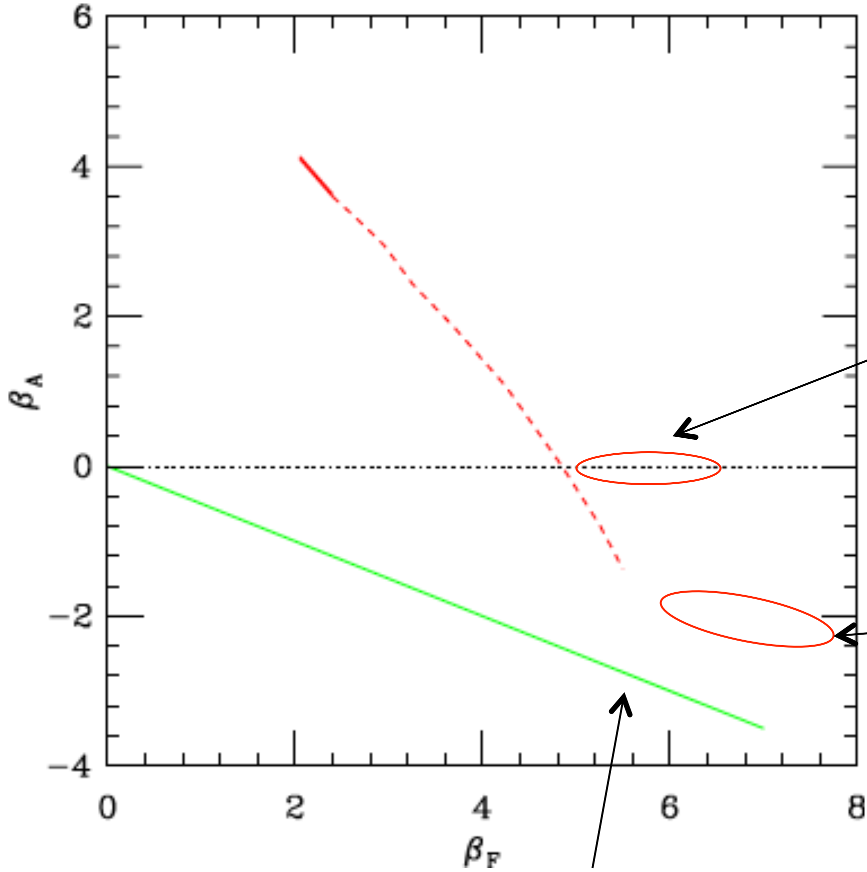


Approximate phase diagram

fundamental-adjoint plaquette action

1-loop Symanzik +adjoint plaq is very similar)

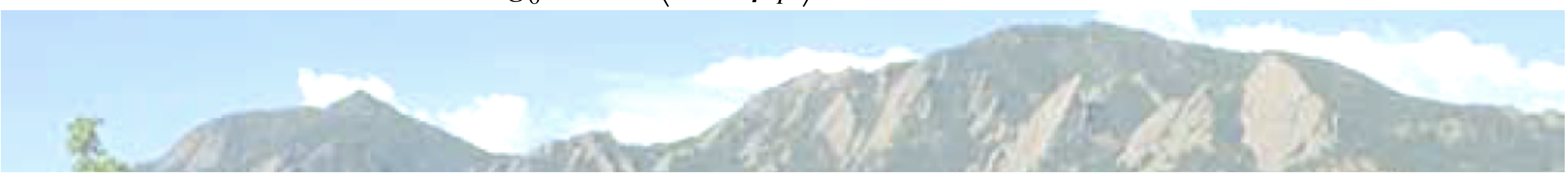
SU(3) gauge with N_f=12 fundamental flavors



MCRG at β_A=0 (1004.1004)
remained inconclusive
(too close to crossover)

This work: β_A/β_F=-0.25
gives clear signal

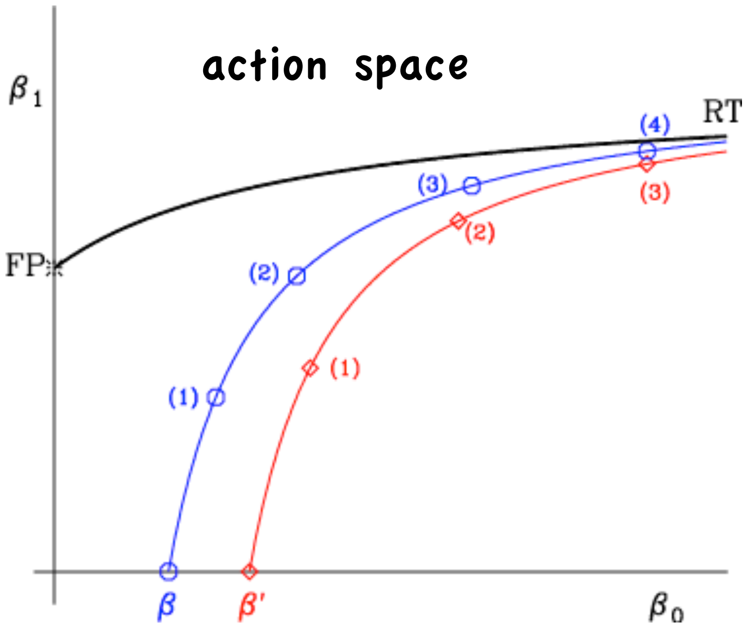
$$\frac{2N_c}{g_0^2} = \beta_F\left(1+2\frac{\beta_A}{\beta_F}\right)=0$$



The step scaling function & MCRG

$s_b(\beta) = \beta-\beta'$ where the lattice correlation length $\xi(\beta)=2\xi(\beta')$

MCRG finds (β,β') pairs by matching blocked lattice actions



Two actions are identical if all operator expectations values agree

Match operators (local expectation values) after several blocking steps

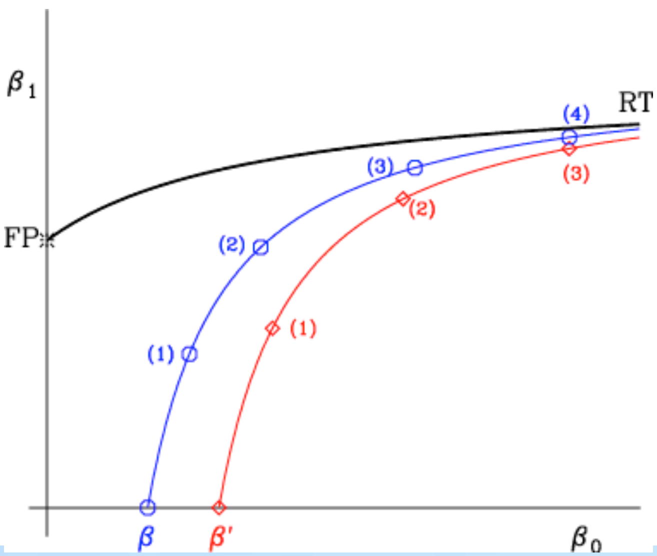
MCRG – finite volume corrections

Two basic steps:

1.Matching: compare operators after n_b/n_b-1 blocking on the same volume

$$\text{if } \langle O(\beta; n_b, L_b) \rangle = \langle O(\beta'; n_b - 1, L_b) \rangle$$
$$\Delta\beta(\beta; n_b, L_b) = \beta - \beta'$$

$L_b = L / 2^{n_b}$ is the last blocked volume, same for both sides!



MCRG – finite volume corrections

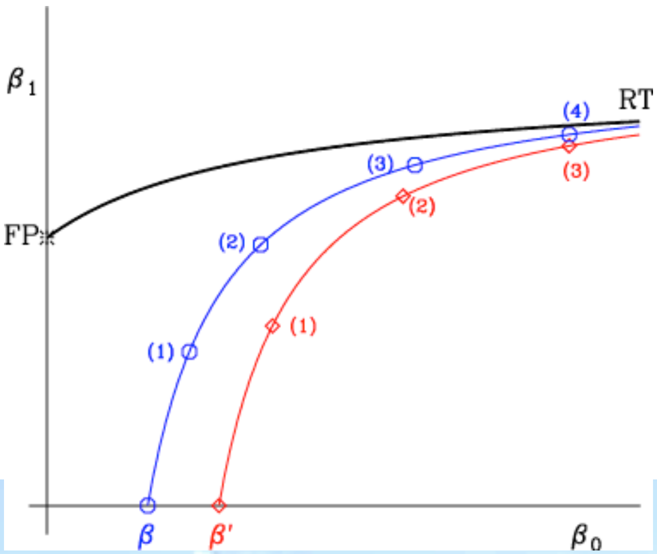
NEW!

2. Optimization: tune the RG parameter α such that consecutive steps predict the same Δβ:

$$\Delta\beta(\beta; n_b, L_b, \alpha_{opt}) = \Delta\beta(\beta; n_b - 1, L_b, \alpha_{opt})$$

Requires matching on L →L/2 volumes

Requires matching on L/2 →L/4 volumes



MCRG – finite volume corrections

NEW!

Example:

1.Matching:

at β: block $32 \rightarrow 16 \rightarrow 8 \rightarrow 4 \rightarrow 2$

at β': block $16 \rightarrow 8 \rightarrow 4 \rightarrow 2$

gives $\Delta\beta(\beta; n_b=4, L_b=2)$

at β: block $16 \rightarrow 8 \rightarrow 4 \rightarrow 2$

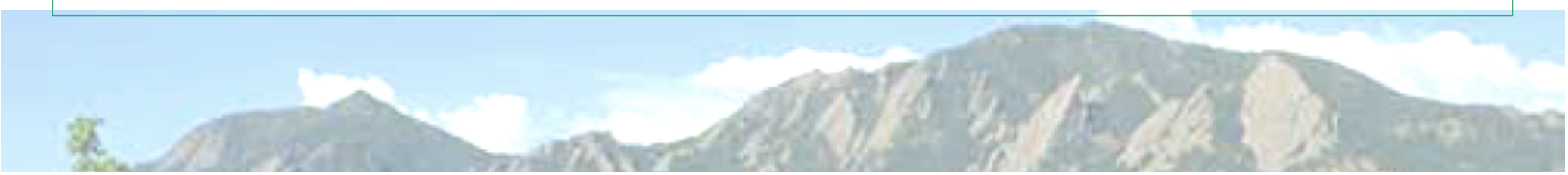
at β': block $8 \rightarrow 4 \rightarrow 2$

gives $\Delta\beta(\beta; n_b=3, L_b=2)$

2.Optimization: compare

$$\Delta\beta(\beta; n_b=4, L_b=2, \alpha) = \Delta\beta(\beta; n_b=3, L_b=2, \alpha)$$

Requires 3 volume sets : 32,16,8



Controls & checks

I match 5 operators
use n_b=4/3/2 and n_b=3/2/1 levels of blocking
use $32^4 \rightarrow 16^4 \rightarrow 8^4 \rightarrow 4^4$ and $24^4 \rightarrow 12^4 \rightarrow 6^4$ volumes

Mass dependence

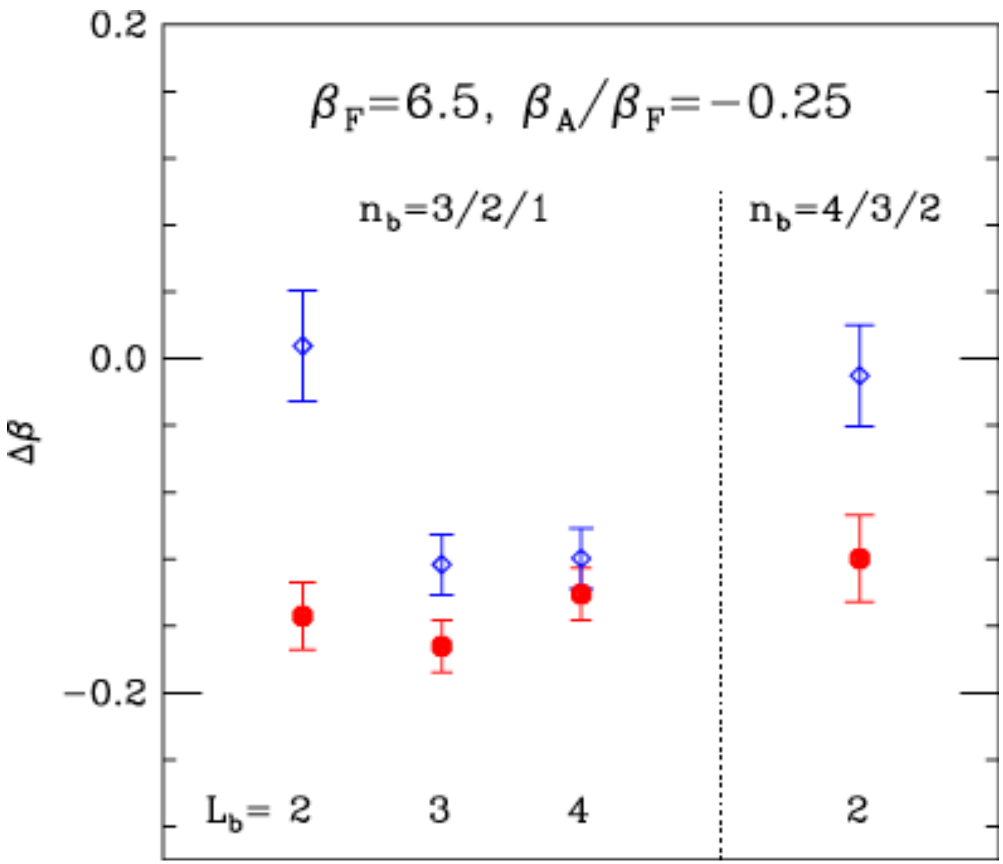
This should all be done at m=0.

I choose my masses small and scale them according to γ=0
(but even γ=1 would not make a difference) :

L_{sym}: 32 → 16 → 8 → 4

m_{sym}: 0.0025 → 0.005 → 0.01 → 0.02

Finite volume corrections in optimization



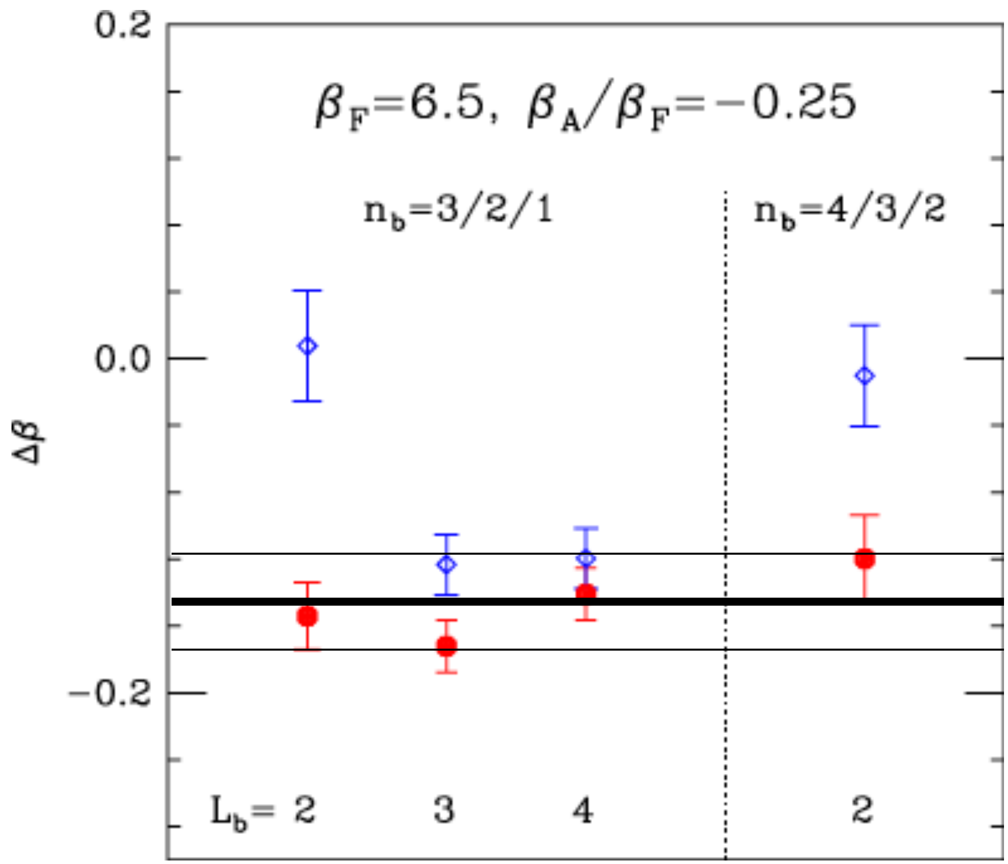
Fixed β_F=6.5
different volumes,
blocking levels

Red: volume corrected
Blue: volume not corrected

L_b: final blocked volume

Errors are combination of systematical and statistical

Finite volume corrections in optimization



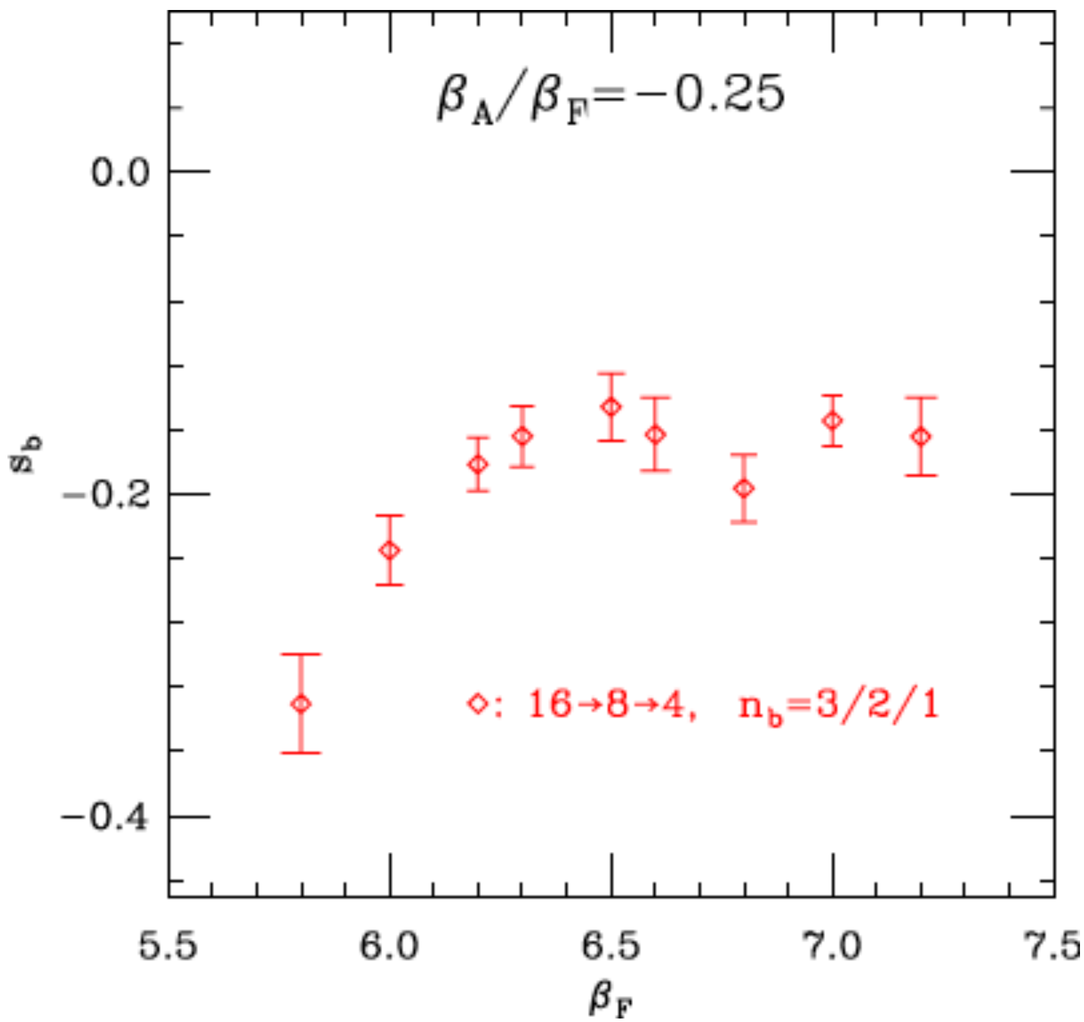
Fixed β_F=6.5
different volumes,
blocking levels

Red: volume corrected
Blue: volume not corrected

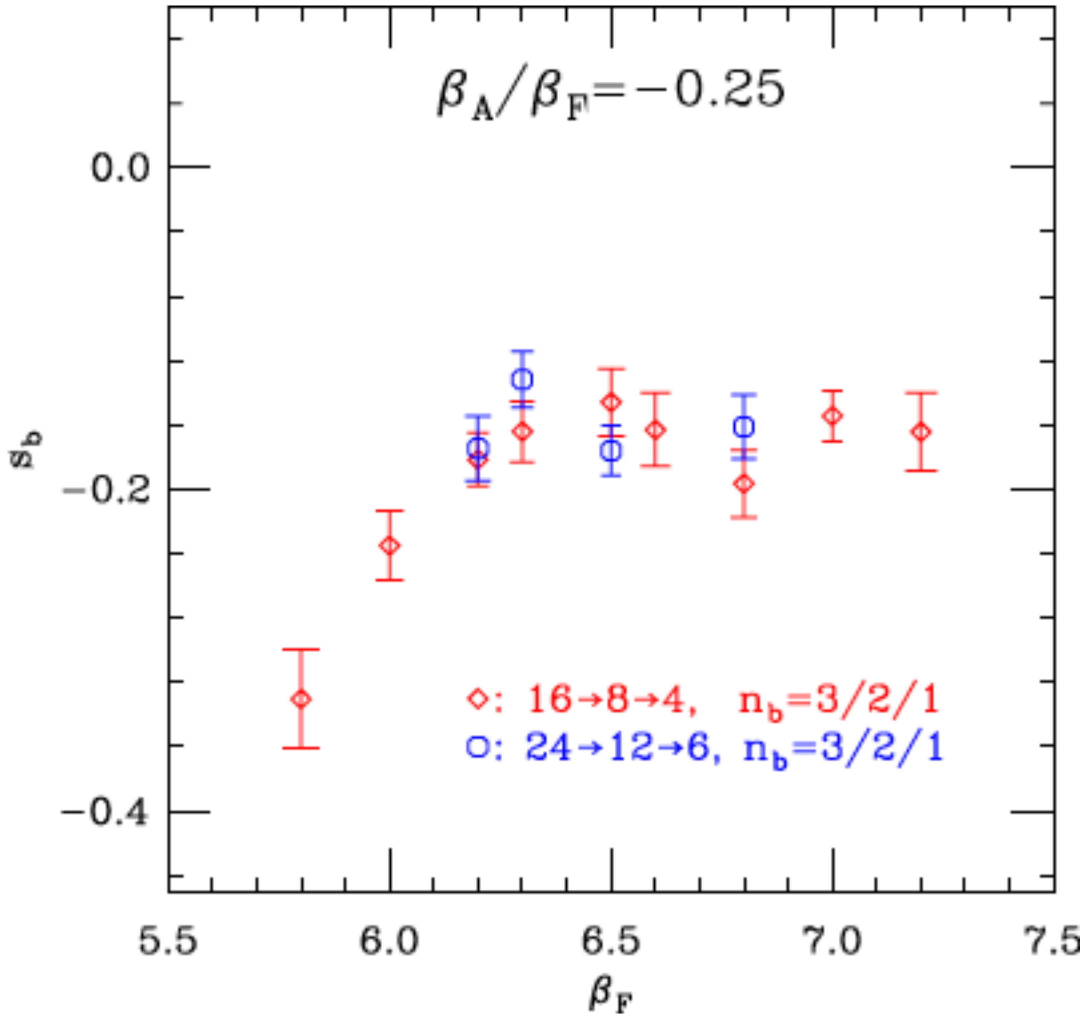
After volume correction all volumes, both blocking levels give consistent results

Errors are combination of systematical and statistical

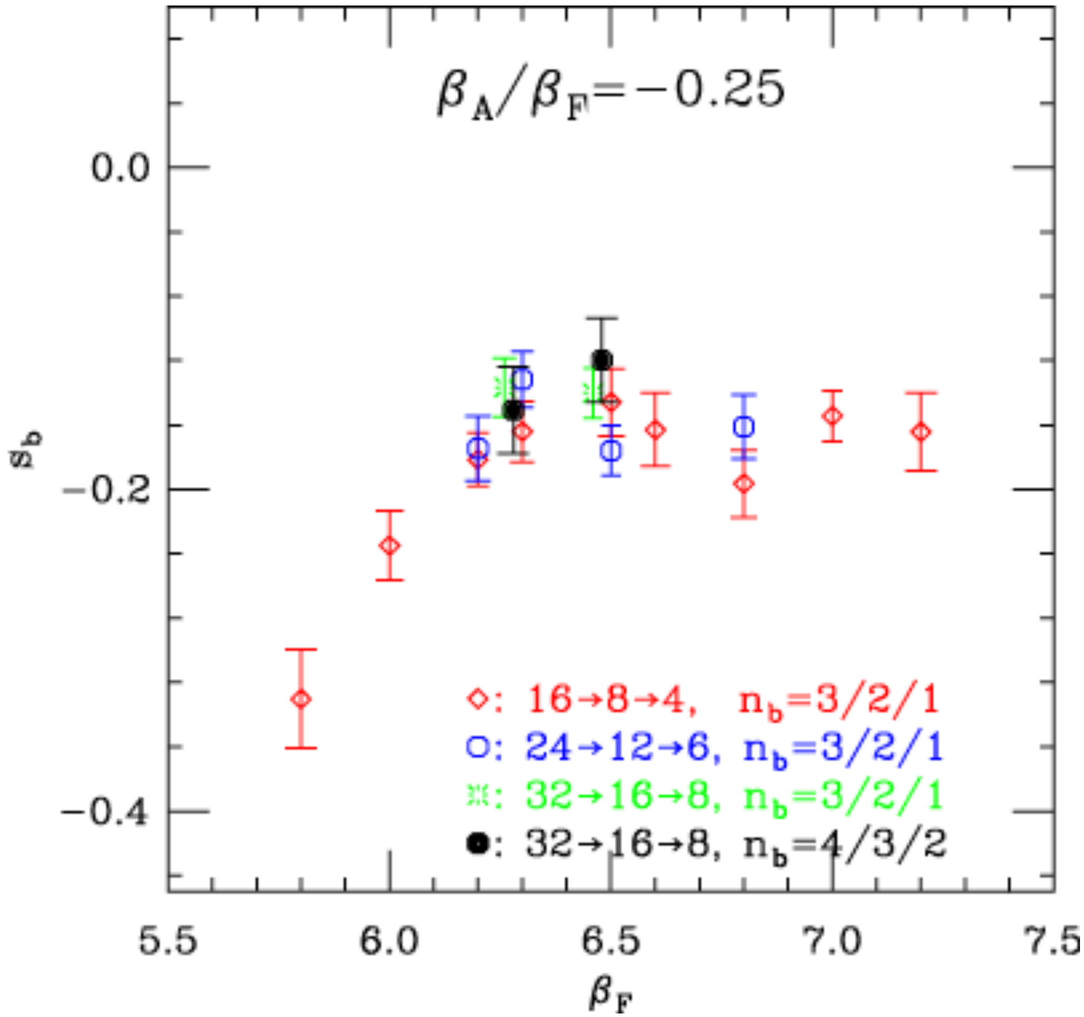
The step scaling function 16→8→4



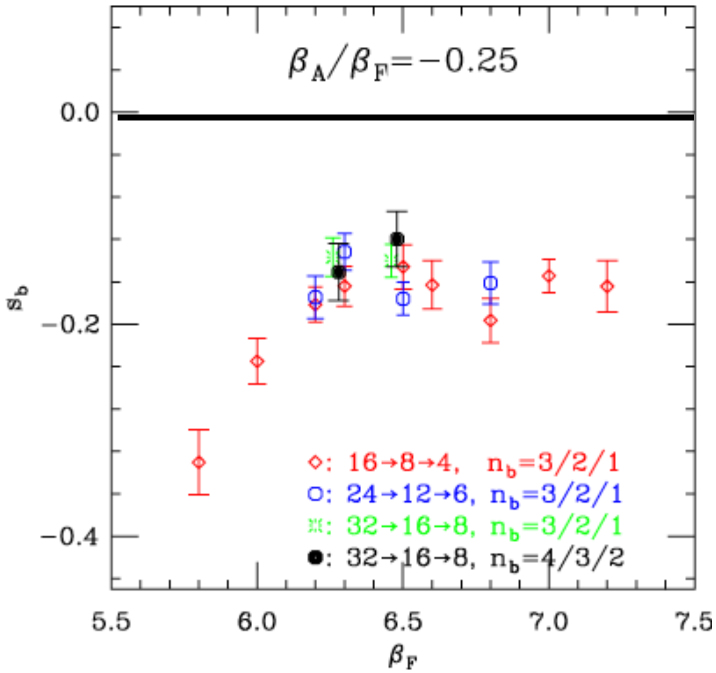
The step scaling function: 24→12→6



The step scaling function: 32→16→8



The step scaling function



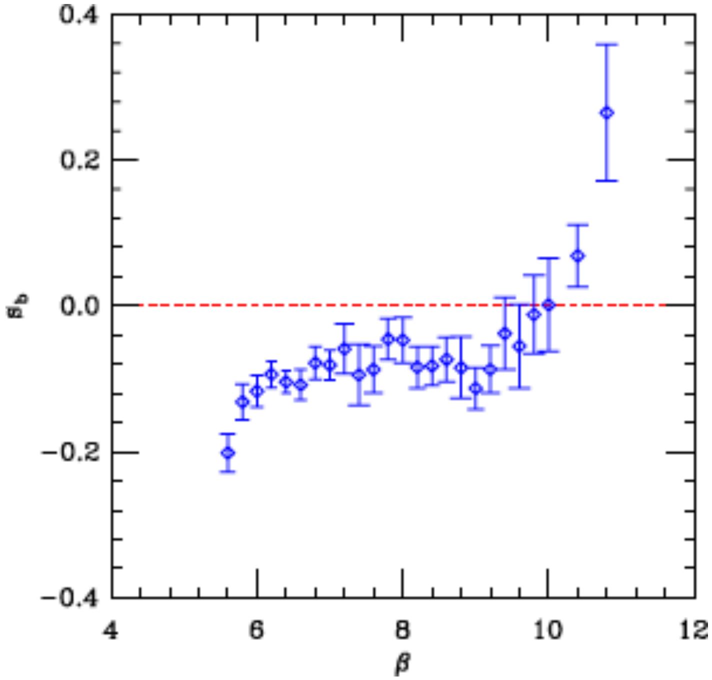
At $\beta_F=\infty$ the step scaling function $s_b>0$

In the investigated β range it is negative

→ There has to be an IRFP (around/above β=11.0)

→ Indicates a conformal system

The step scaling function



With $\beta_A/\beta_F = -0.15$ the IRFP is closer and I can find the IRFP

(16→8 →4 matching)

Summary of MCRG matching

MCRG requires matching on identical volumes for optimization

- Optimized, volume-matched MCRG gives consistent results for Δβ (the step scaling function)
- s_b for Nf=12 fermions, SU(3) gauge is consistently negative, indicating an IRFP and conformal dynamics

Studies in the strong coupling

Why now

- There is a contradiction between MCRG & BMW results.
  We are investigating different coupling regions:
  - MCRG : $6/g^2 \sim 3.7$
  - LHC : $6/g^2 \sim 2.2$

The action

- Fundamental-adjoint gauge : $\beta_A/\beta_F = -0.25$
- nHYP projection has numerical problems when the smeared link develops near-zero eigenvalues
  - small tweak of the HYP parameters can fix that!
    $(\alpha_1,\alpha_2,\alpha_3)=(0.40,0.50,0.50)$ will do the trick

(Thanks, Stefan S.)

Studies in the strong coupling

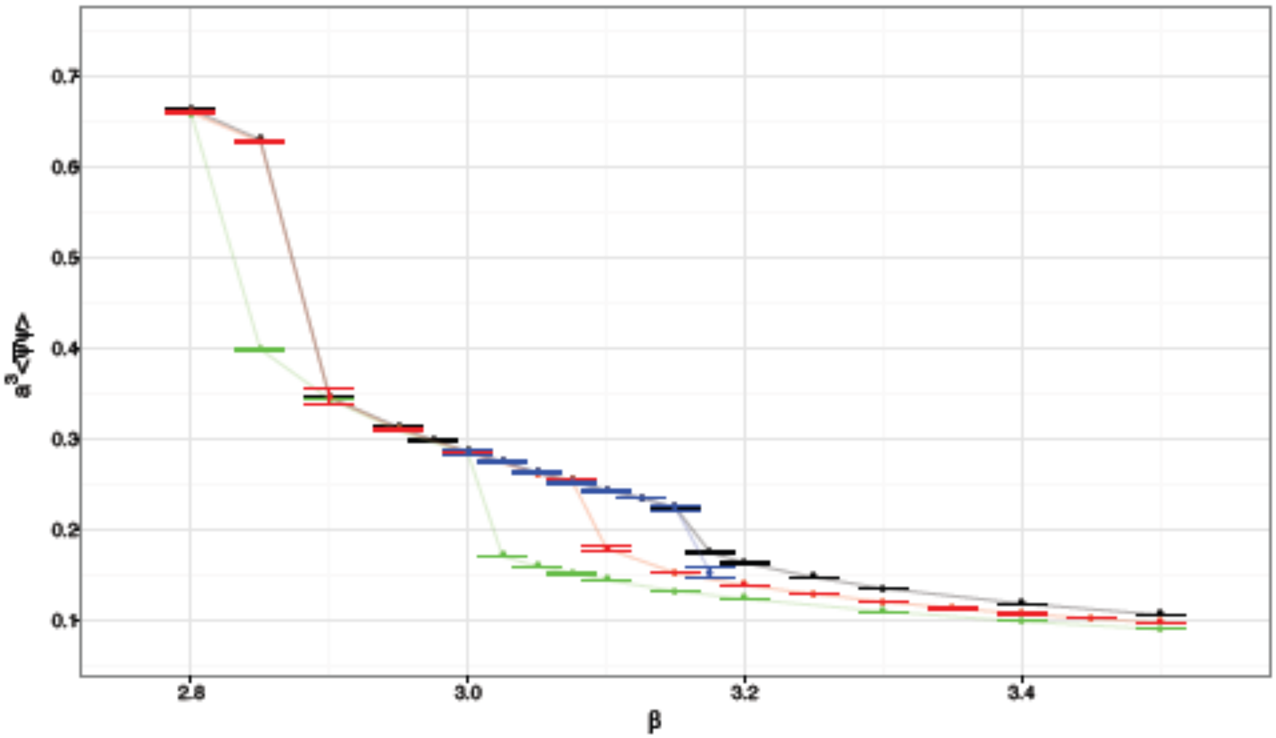
N_f=12 and 8 flavors, SU(3) gauge + nHYP' fermions

(A. Cheng, A.H., D. Schaich)

Previous results on the phase stucture

Groningen-INFN group found 2 first order transitions (2010)

m=0.025, N_T=6,8, 10 and T=0 (Asqtad fermions)

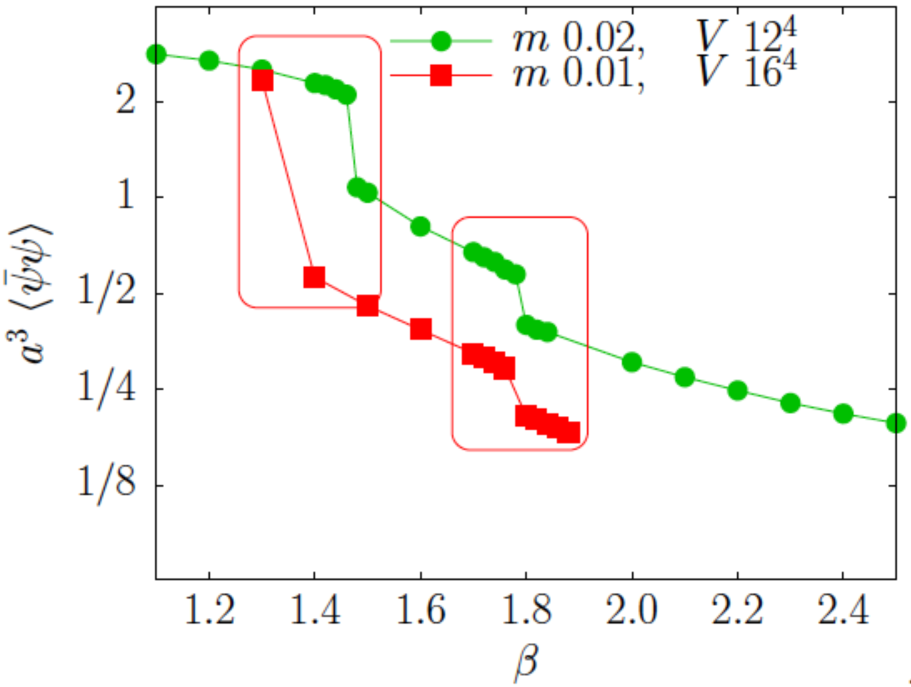


Previous results on the phase stucture

BMW collaboration (C. Schroeder's Latt'11 talk)

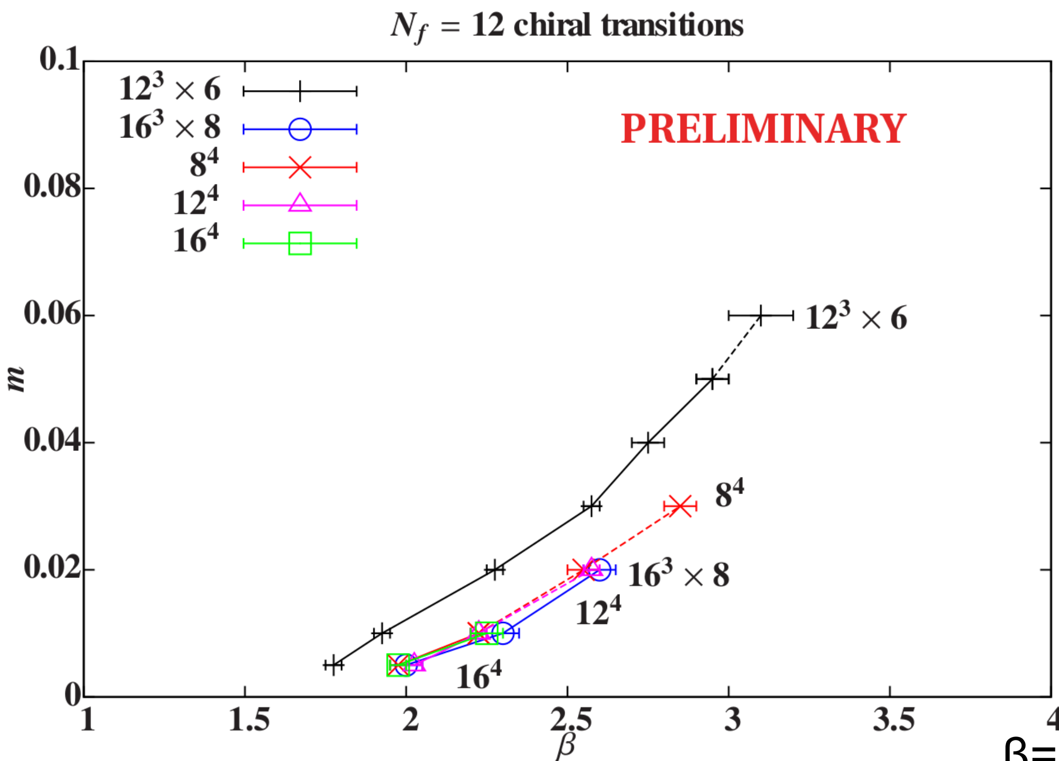
2 transitions

(2 stout fermions)



Phase diagram

The first (strong coupling) phase transition on β-m plane



β=12/g^2

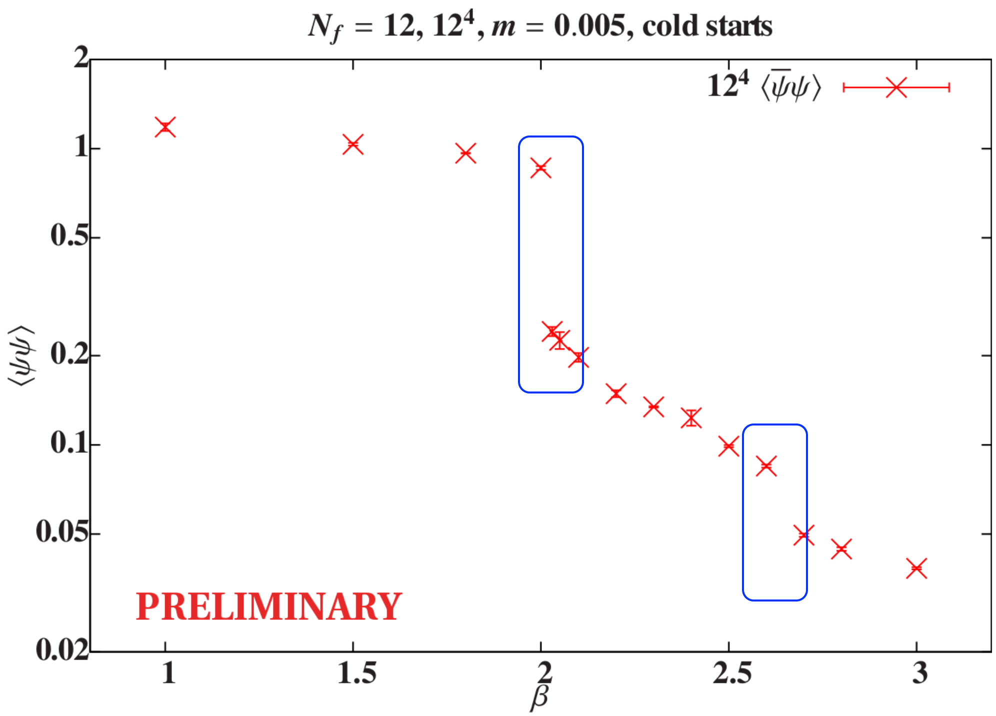
First order transition: solid
crossover : dashed lines
observe the small fermion mass!

Symmetric lattices show first order transition only at small mass

First order finite temperature phase transition converges to a zero temperature "bulk" transition

Phase diagram

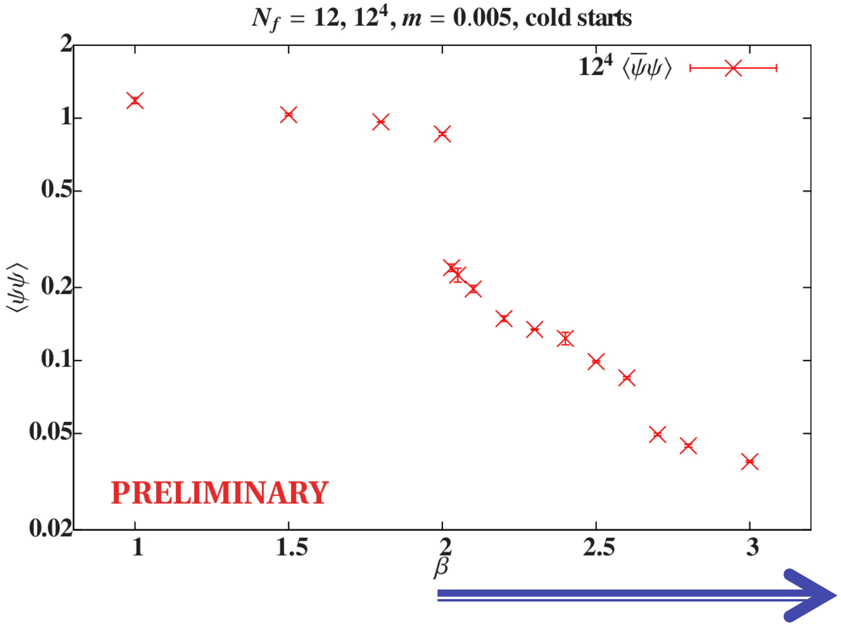
Where is the second transition? Look at $\langle \bar{\psi}\psi \rangle$ $(12^4$, m=0.005)



The second jump is tiny, but the chiral condensate is discontinuous

Phase diagram

What are the 2 (3) phases?



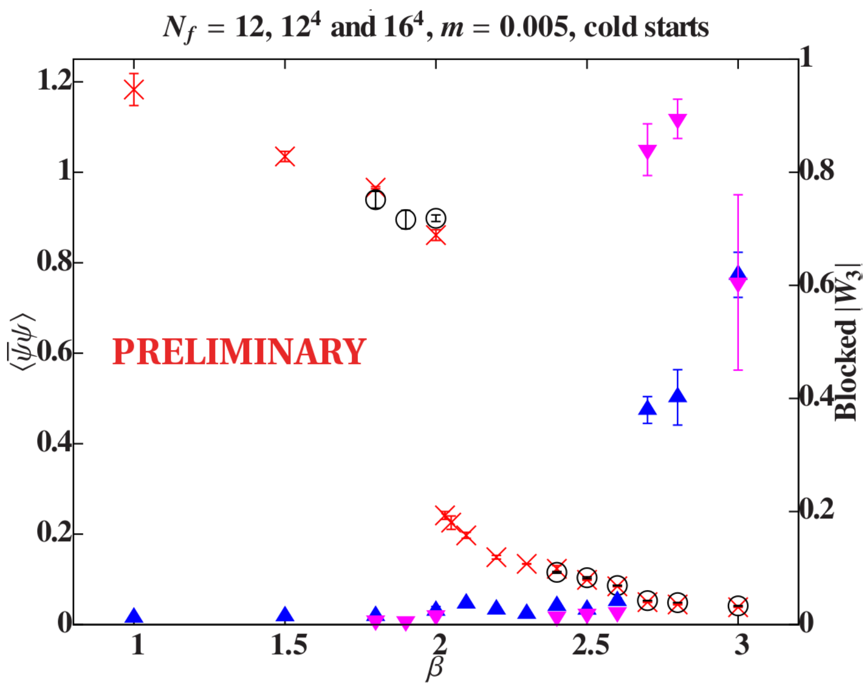
Chiral condensate extrapolates to zero in the chiral limit on the weak coupling side of the “big” jump

→ Chiral restoring transition

Is it deconfining?

Phase diagram

Is it deconfining? Polyakov line is very noisy but the blocked Poly line is sensitive:



Blocked Poly line is measured on RG blocked lattices:

- improved Poly line

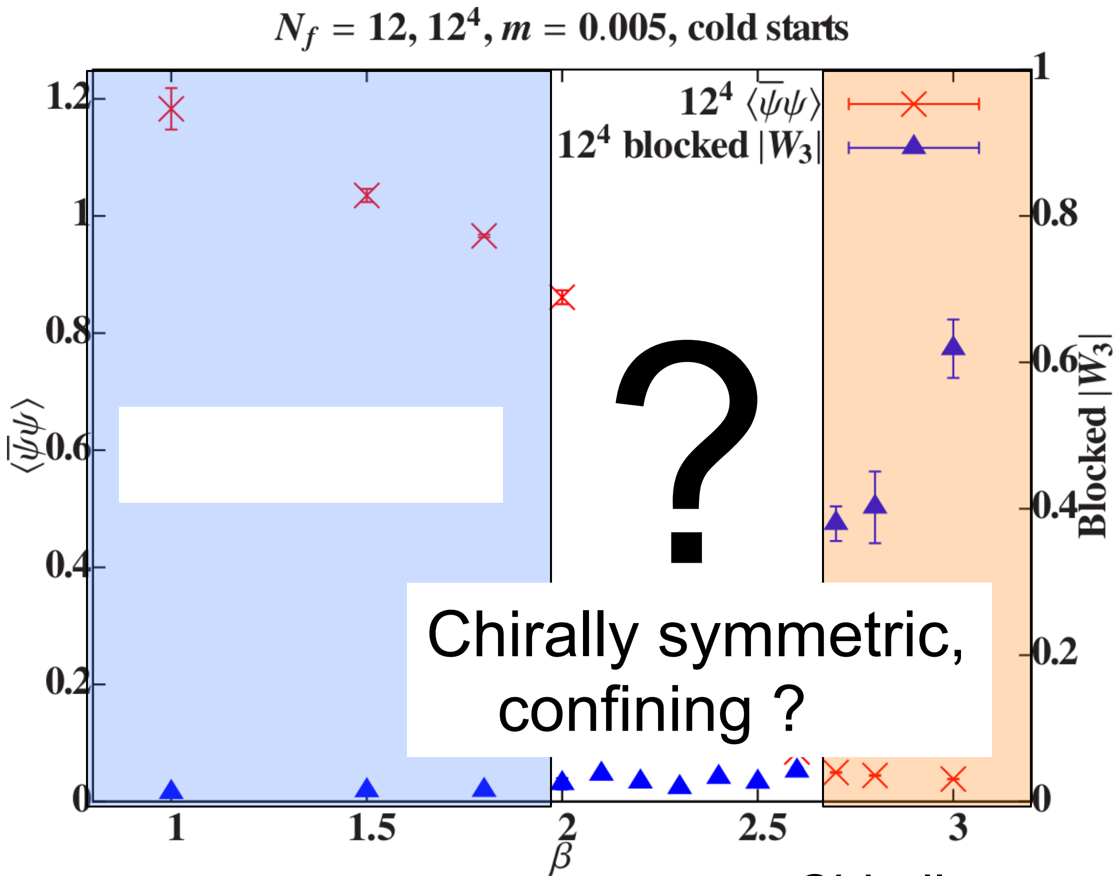
or

- Poly line on renormalized trajectory, after removing UV fluctuations

The blocked Polyakov line sees the “weak” transition strongly but hardly changes at the “strong” transition

It does not go away on larger lattices :compare 12^4 and 16^4

Phase diagram

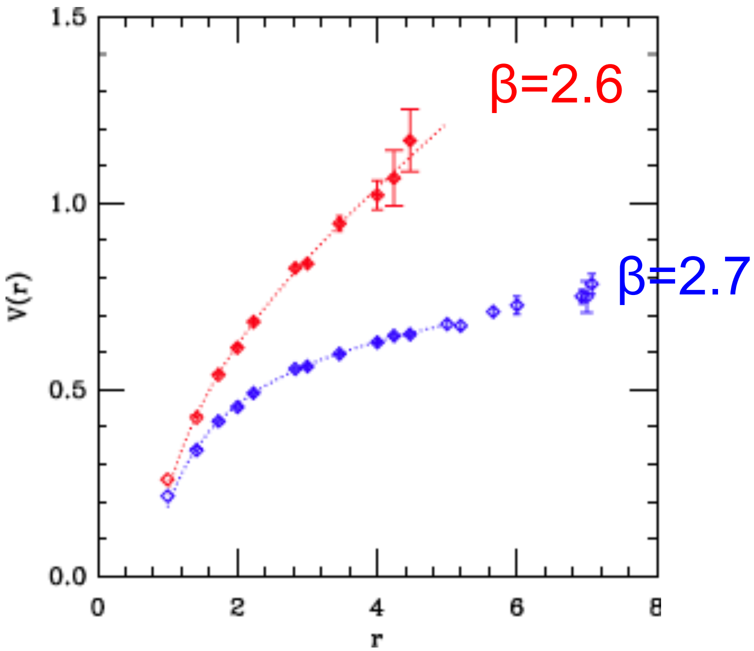


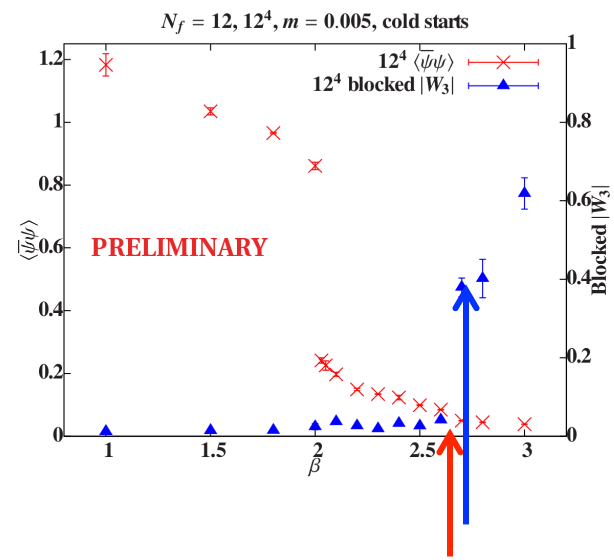
Chirally broken,
confining

Chirally symmetric,
deconfined

Intermediate phase:

- Chirally symmetric: $\langle\bar{\psi}\psi\rangle \to 0$ as m→ 0
- Confining: static potential on 12^3,16^3 volumes show a linear term:
  r_0=2.1 – 2.7, $\sqrt{\sigma}$ =0.40 -- 0.48



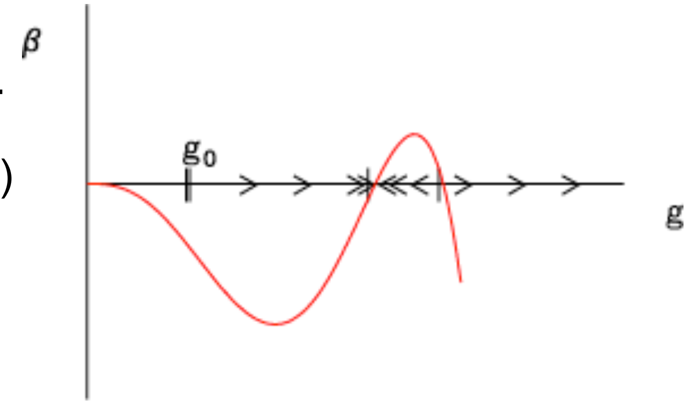


But such phase is not supposed to exist in QCD….

Intermediate phase

Confining and chirally symmetric:

Could it be the strongly coupled non-AF phase? (Kaplan, Son, Stephanov)



N_f=12 has 2 first order transitions:

Is there another relevant direction that defines the continuum limit? $(\bar{\psi}\psi)^2$??

How does this change with N_f?

Try N_f=8,10 (8 is in progress)

The saga continues….

What we know:

- MCRG indicates an IRFP at relatively weak coupling
- Both the finite temperature and symmetric lattices show first order phase transitions, but only at small masses
- The chiral and deconfinement transitions are well separated
- There appears to be a phase that is chirally symmetric but confining

A lot of unanswered questions:

- Are both transitions converge to a bulk one?
- What is the hadron spectrum of the intermediate phase?
- What is this intermediate phase?